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On limitations of the ultrasonic characterization of pieces manufactured with highly attenuating materials

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Abstract

Some technical aspects of two Spanish cooperation projects, funded by DPI and Innacto Programs of the R&D National Plan, are discussed. The objective is to analyze the common belief about that the ultrasonic testing in MHz range is not a tool utilizable to detect internal flaws in highly attenuating pieces made of coarse-grained steel. In fact high-strength steels, used in some safe industrial infrastructures of energy & transport sectors, are difficult to be inspected using the conventional “state of the art” in ultrasonic technology, due to their internal microstructures are very attenuating and coarse-grained.

It is studied if this inspection difficulty could be overcome by finding intense interrogating pulses and advanced signal processing of the acquired echoes. A possible solution would depend on drastically improving signal-to-noise-ratios, by applying new advances on: ultrasonic transduction, HV electronics for intense pulsed driving of the testing probes, and an “ad-hoc” digital processing or focusing of the received noisy signals, in function of each material to be inspected.

To attain this challenging aim on robust steel pieces would open the possibility of obtaining improvements in inspecting critical industrial components made of highly attenuating & dispersive materials, as new composites in aeronautic and motorway bridges, or new metallic alloys in nuclear area, where additional testing limitations often appear.

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1. Introduction. Some inspection problems in attenuating materials

In industrial strategic applications, with great demands nowadays, the use of certain critical components is needed, where materials of very high resilience and free of internal failures must be used. Typical examples of this are the austenitic steels of high resistance (alloys with chromium, nickel, or manganese) used in components for high pressure or strain in petrochemical, nuclear and transport sectors. The inner parts of these components are

difficult to inspect with ultrasonic waves because they are constructed with highly attenuating materials having internal coarse grains with strong dispersive effects on the acoustic propagation.

Only the current use of ionizing radiations, with high economic costs and the typical associated problems related to personal health and environmental safety, is conventionally allowing a control of faults in this type of structures.

Nevertheless, it seems that it would be possible to attempt a future development of improved inspection systems for ultrasonic imaging of the interior of high-safety critical components used in these industrial sectors. This aim would include the definition or development of special broadband ultrasonic transducers at intermediate frequencies in the megaHertz range, seeking for the optimization of the testing sensibility in these types of attenuating and dispersive materials, and the prior employment of predictive numerical simulations of pulsed ultrasonic responses in through-transmission and pulse-echo testing regimes.

Other aspects to be tested are alternative options for optimizing the involved control of the transduction process and the advanced processing of the ultrasonic echoes, by integration or design of efficient electronic systems for generation, reception, and treatment (de-noising, focusing, etc.) of the acquired echo-signals, which must be adapted to the requirements of the selected transducers and the special materials under analysis in each case.

As a particular technical detail to be taken into account, the driving circuit systems for the electrical transducer excitation will have to deliver a larger pulsed energy than in the conventional inspection applications, by means of an adequate design of the pulse generator with an efficient electrical coupling; the objective would be to attain a good ultrasonic penetration giving flaw echoes with an acceptable signal-to-noise ratio.

Finally, the disposition of specific processing algorithms, for the enhancement of the signals received from the possible flaws, could be needed in some cases with high noise levels in the ultrasonic echoes.

2. A first testing of ultrasonic propagation

In order to study limitations of the currently disposable ultrasonic tools for the testing of industrial pieces manufactured with a particular attenuating and dispersive material, several configurations of ultrasonic analysis, based on different equipment of END and specific transducers, were selected for these types of inspections, which are available in the laboratories of our centers. They were preliminarily applied in the testing of a steel piece with coarse grain in its internal structure, and in a second stage a piece containing artificial flaws was tested. In the first step, simple inspections were made by means of ultrasonic pulses in a mono-channel scheme and using the pulse-echo and through-transmission testing modes for direct contact between the transducer and the piece under inspection.

The objectives of this work were to study the ultrasonic propagation into these special metallic materials and mainly to analyze the viability of ultrasonic testing in these traditionally difficult alloys. For this reason, in addition, laboratory experiments were also made using phased-array configurations, with equipment for inspection available, of type multichannel and of latest generation (Olympus-Panametrics and General Electric), as it is shown in the following section 3.

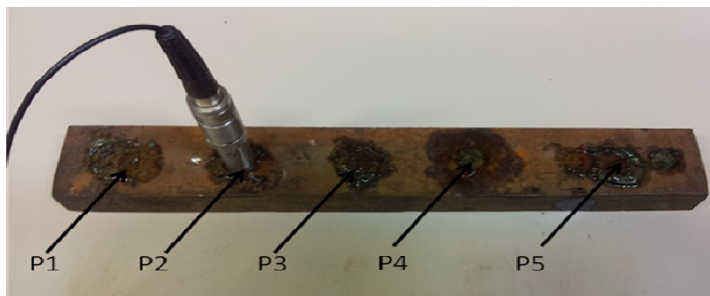


Figure 1. Steel piece containing coarse grains with the points P_i where measurements were taken

As the first experimental reference, a generic piece of coarse-grained steel (manganese alloy) was used, analyzing the pulses of echo-response for transduction probes of different relatively high-frequencies, as a testing of the ultrasonic propagation conditions, in this material without artificial flaws.

Figure 1 shows the disposition of the experiment with one of the involved ultrasonic probes. Five transducers were used with frequencies: 1, 2.25, 3.5, 5 and 15 MHz, under high-voltage driving. In figure 2, a selection of some of the responses obtained with these transducers, from several measurement points (P_i), are shown. Three successive main echoes appear coming from the opposite wall of the piece in all the cases.

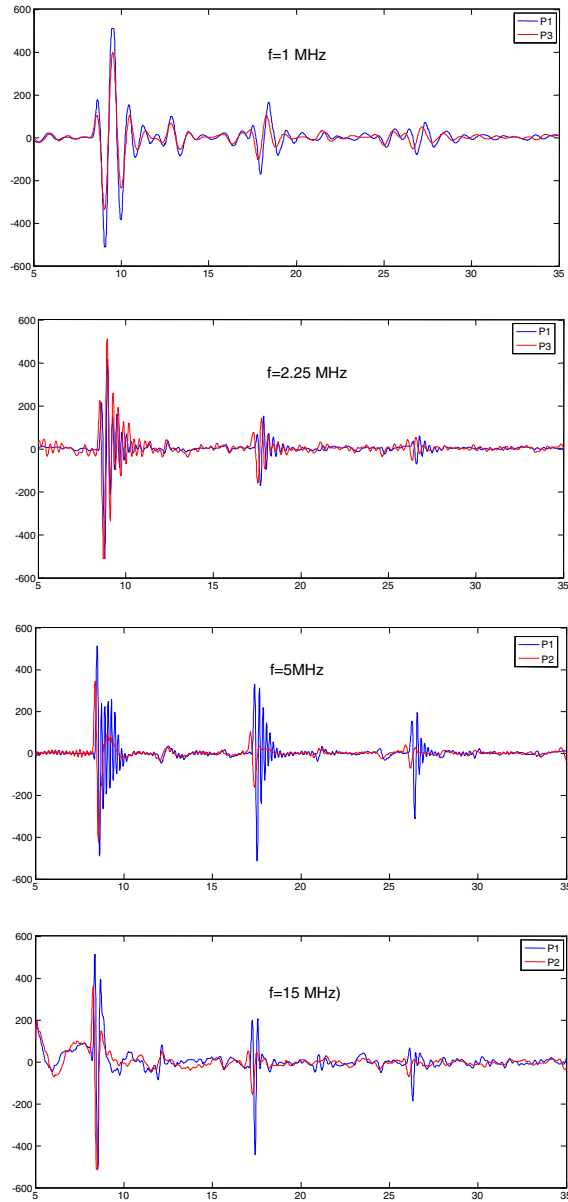


Figure 2. A selection of echo responses in points (P_i) of the coarse-grained steel piece.

In these responses, effects of scattering (Watterman and Truell, 1961) and attenuation (He, 1999) are present. These effects can be estimated in the fall and deformation (increasing with frequency) of the successive pulses and in the level of noise signals appearing between the three main pulses, which are related to reflections from the material internal structure. Nevertheless, these attenuating and dispersive characteristics of the echoes in principle seem to be not excessively strong so as to mean that the performing of an ultrasonic testing and characterization of this type of piece were impossible.

Another aspect that could complicate the data interpretation during the ultrasonic inspection is that the piece material behaves not as homogeneous in its internal mechanical characteristics, since the echo-measures taken in some points show minor attenuation or deformation compared with the reflections acquired in other sites.

An important effect observed in these test results is that in some cases multiple reflections (reverberations) appear, perhaps due to resonance phenomena related to local in-homogeneities in the metallic alloy. A deeper analysis of these propagation and reflection problems would be needed in each particular case because in this technological field there are hardly any experimental data (Garnier and Solna, 2010; Holm and Sinkus, 2010).

3. Flaw detection results in attenuating steel

More specific ultrasonic echo-analyses were made using mono-channel configurations in direct contact with a piece having artificial flaws. The equipment of inspection, Olympus EPOCH 6000, was used with transducers, Panametrics, from 1 to 5 MHz; by means of this rather simple testing arrangement, it was not possible to obtain useful echo-signals from internal flaws. This seems to result from the masking of the echographic signals (tied to the internal flaws), produced by the reflected grain noise and by the notable attenuation introduced into this type of dispersive material with a notable internal scattering of the propagating ultrasonic waves. Using the mono-channel ultrasonic option, uniquely acceptable results were obtained when the through-transmission testing mode was employed, which only would be applicable in the inspection of pieces accessible from both sides.

Nevertheless, if the pulse-echo mode option is needed, because of accessibility problems or if deep flaw data must be measured, then a possibility would be to adopt more sophisticated options, for instance by adding complex signal processing procedures (Hirokawa; Hirokawa, 2008; Rodríguez et al., 2004) with the aim of eliminating an important part of the noise corrupting the echo-signals (with origin in the material scattering associated to the coarse grain of the internal structure of these steel pieces, which are difficult to inspect). This processing option for SNR improvement could also be complemented by simulation and developing of new types of pulse generators and circuit interfaces for high-voltage driving of the transducer, where NDE responses are improved with selective damping and tuning networks (Ramos et al., 2000; Ramos et al., 2004).

Finally, another possible very good solution, applicable in the pulse-echo inspection mode, is the application of more complex ultrasonic equipment based on multichannel topologies, oriented to create focused ultrasonic beams by means of piezoelectric arrays and electronic focusing.

3.1. Ultrasonic analysis with electronically focused phased-arrays

Bearing in mind that the use of commercial ultrasonic inspection equipment of the mono-channel type, working with the pulse-echo option, did not result in a possibility of inspecting faults inside the considered piece of attenuating steel, we applied the array technologies available in our laboratories, adapted to this specific case, in order to make a dynamic electronic focusing of the ultrasonic beams.

The first results, obtained with this multichannel technology of image formation are encouraging, since, faults of 5 mm inside the abovementioned piece can be clearly detected in the pulse-echo mode. The tests were performed by applying the commercial NDT models: a) Omniscan (Olympus) with a 36 element - 5 MHz array, and b) Phasor (General Electric) with a 16 elements - 4 MHz array. In Figures 3 and 4, some of the imaging results, obtained in these array inspections, are depicted. The searched flaws can be clearly appreciated in both cases.

4. Conclusions

From the inspection results obtained with the application of two technologies of the “phased array” type, and using a manual testing in contact with the surface of a steel alloy piece, it seems that both options could be a valid solution for the identification of internal flaw indications in this type of pieces traditionally difficult to be inspected. Using this multichannel testing, some flaws with diameter around 5 mm were clearly detected.

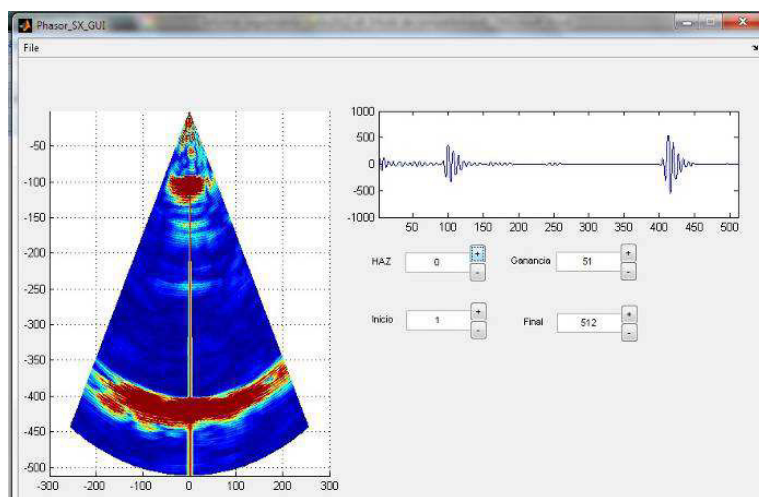


Figure 3. Inspection results with the Phasor NDT unit

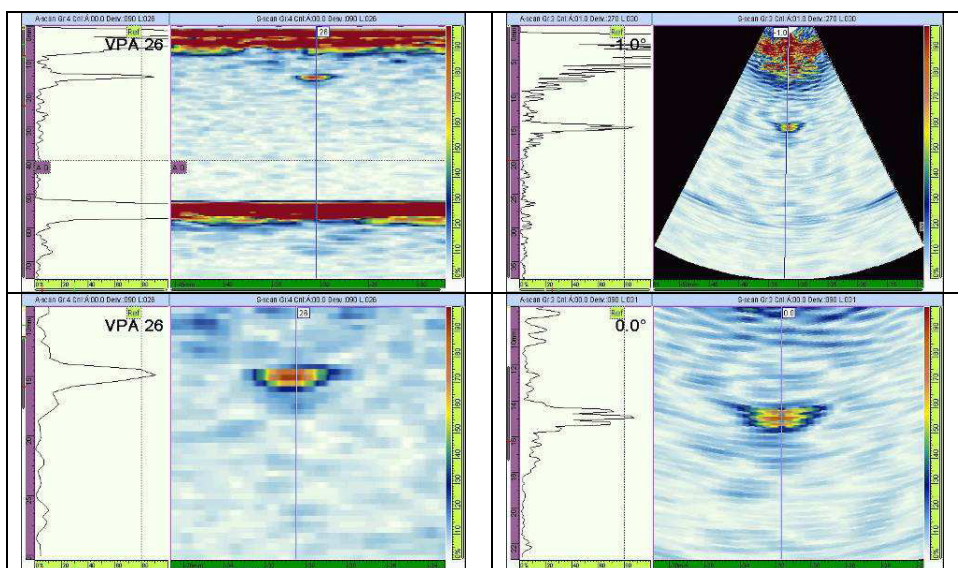


Figure 4. Some inspection results with Omniscan NDT unit

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